

Land and sea thunderstorms—a comparative study

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Abstract : A comparative study of land and sea thunderstorms in relation to their onset times, duration and magnitudes is reported here. Their electrical behaviours are derived from the round-the-clock records of VLF atmospherics. The results have been interpreted by considering the distribution of the effective noise sources around the observing site

Keywords : Land and sea thunderstorms, comparative study, VLF atmospherics.

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1. Introduction

Atmospherics are known to have a close association with thunderstorms and it has been studied in different parts of the globe from time to time [1-7]. Some reports have already been made on the intimate connection of LF-VLF atmospherics with different types of thunderstorms over Calcutta [8,9] (22°34'N, 88°24'E). In Poona (18°31'N, 73°52'E) Chiplonkar *et al* [10] reported an unusual rise or fall in atmospheric activity at night. The origin of this variation was not clearly explained though there was some indication that the fall may be related to the oceanic storms. Available scattered information with insufficient observational data demand a further investigation of the atmospherics during thunderstorm over this region. In fact, study of the electrical characteristics of such storms has its due importance in forecasting their occurrences which produce serious weather hazards over the Gangetic West Bengal.

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For the last two decades, we are engaged in the studies of atmospherics in the VLF band over Calcutta. An analysis of the data revealed some interesting results during tropospheric disturbances due to land and sea thunderstorms. It is the purpose of this paper to make a comparative study between them.

2. Observations

It is well known that the life time of a thunderstorm mainly consists of three different stages, viz. developing, mature and dissipating which are supposed to contribute the major changes of the integrated field intensity of atmospherics (IFIA). This idea of three stages of the phenomenon has been utilized to select the samples of IFIA to get the probable characteristics of the effect originating from thunderstorms. Small magnitude fadings or a gradual enhancement followed by a rapid decay corresponding to local precipitation are of distinctly different patterns and hence have been excluded from the analysis.

Occurrence of thunderstorms were ascertained from the reports of the local meteorological office and also as noticed over the observatory. The PPI display in radar observations and the corresponding polar diagrams are made on an hourly basis in the local meteorological observatory. Usually the cloud cells owe their origin to isolated or scattered precipitation echoes as we observed on the PPI scope, which after sometimes increase in number and size and subsequently form a full-fledged storm. During the local premonsoon (March to May) and monsoon (June to September) seasons, the radar observations indicate a considerable number of thunderstorms both over land and sea while postmonsoon (October to February) thunderstorms are only a few.

Daily records from June 1976 to May 1991 have been analysed here in relation to premonsoon, monsoon and postmonsoon land thunderstorms. The night-time radar observations of oceanic thundercells for the same period have been obtained from the local meteorological observatory at Calcutta. A schematic diagram showing the topography in relation to 400 km range radar has been published elsewhere [11] indicating location of land thundercells. The number of very prominent land and sea thunderstorms obtained from PPI observations associated with IFIA considered here, are given in Table 1.

Table 1. Occurrences of land and sea thunderstorms associated with IFIA.

Season	Land thunderstorm	Sea thunderstorm
Premonsoon	204	157
Monsoon	256	188
Postmonsoon	33	29

3. Results

3.1. Typical records :

Typical records of IFIA at 10 and 20 kHz during land and sea thunderstorms have been shown in Figures 1 and 2 respectively. The typical records show that the effect starts simultaneously at both the frequencies but with different magnitudes.

The records of IFIA in Figure 1 reveal an initial gradual rise (GRA) followed by a sudden enhancement (SEA₁) both during the monsoon and postmonsoon thunderstorms, while during premonsoon thunderstorms the enhancement occurs in three different stages

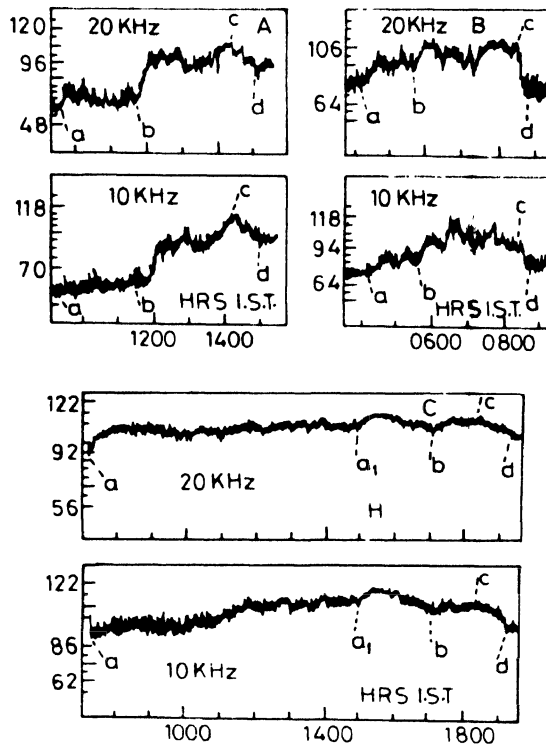


Figure 1. Typical records of IFIA at 10 and 20 kHz during land thunderstorms. The ordinates are in dB above $1 \mu\text{V/m}$. Symbols used are : a—initial gradual rise, a and b—sudden enhancement, c—starting of decay, d—IFIA regains normal level. (The records marked A, B and C are respectively during monsoon, postmonsoon and premonsoon periods).

which are a gradual rise of atmospherics (GRA), first sudden enhancement of atmospherics (SEA₁) and second sudden enhancement of atmospherics (SEA₂). A steady recovery of atmospherics (SRA) follows the sudden enhancement in all the cases.

Sample records of the night-time effects in IFIA at 10 and 20 kHz are also shown (Figure 2). Each record embodies a first enhancement and then a distinct fall. In between these two variations, there is a nearly steady level, in general. This steady level is not very clear in all the samples simply due to reduction in photo copying from the actual records.

3.2. Characteristics :

(a) Land thunderstorms and IFIA

The dominant features of IFIA in relation to premonsoon, monsoon and postmonsoon land thunderstorms have been shown in Table 2. This study has been made by considering the characteristics of the major number of cases.

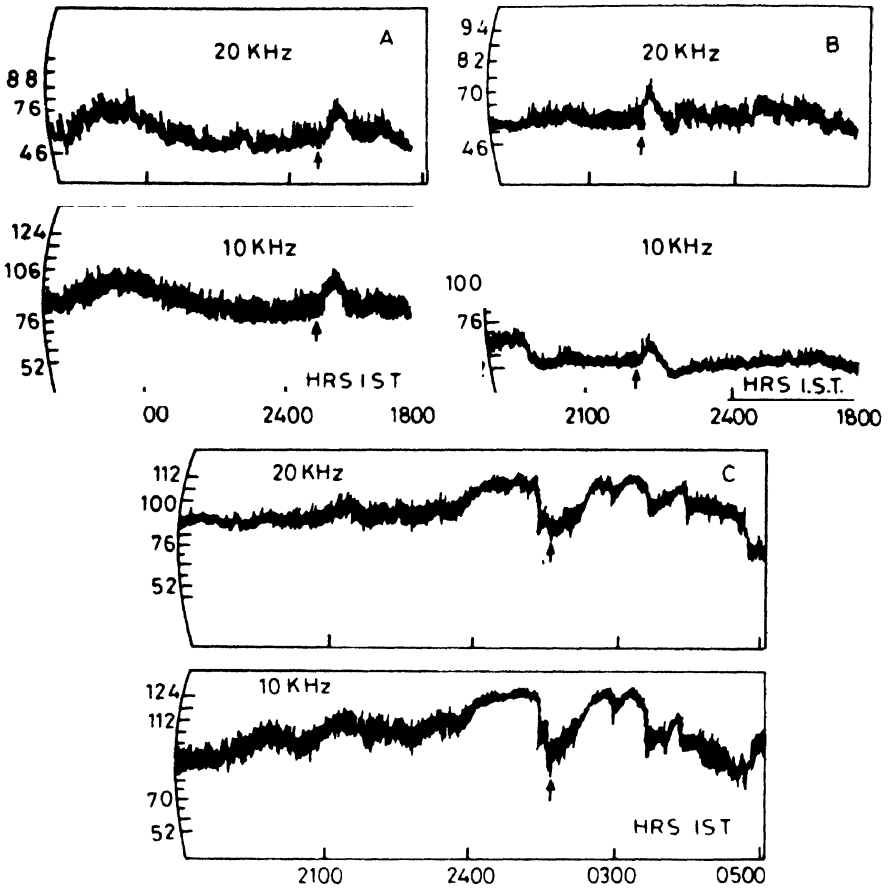


Figure 2. Typical records of IFIA at 10 and 20 kHz during sea thunderstorms. The arrow indicates the time of start of the effect. The ordinates are in dB above $1 \mu\text{V/m}$. (The records marked A, B and C are respectively during monsoon, postmonsoon and premonsoon periods)

Table 2. Distinct features of IFIA at 10 and 20 kHz in relation to land thunderstorm (TS).

Properties	Premonsoon	Monsoon	Postmonsoon
% of SEA_1	100%	100%	100%
% of SEA_2	~ 89%	~ 6%	—
Onset time			
GRA	Prenoon	Prenoon	Prenoon
SEA_1	Latenoon	Around noon	Prenoon
SEA_2	Afternoon	—	—
SEA	Premidnight	Afternoon	Latenight
Duration			
GRA(hr)	1–3	1–3	0–1
$\text{SEA}_1(\text{min})$	0–20	10–30	10–20

Table 2. (Contd.)

Properties	Premonsoon	Monsoon	Postmonsoon
SEA ₂ (min)	0–20	–	–
SRA(min)	30–90	15–45	15–30
Delay between onset			
GRA and TS(hr)	2–7	2–5	2–3
SEA ₁ and TS(hr)	0–3	1–2	1–2
SEA ₂ and TS(hr)	0–1	–	–
Observed rainfall associated with	SEA ₂	SRA	SRA
Change of magnitude			
GRA	High	Low	Low
SEA ₁	Medium	High	High
SEA ₂	Medium	–	–
SRA	High	Low	Low

This study shows that the onset time of SRA for monsoon and postmonsoon months is at afternoon and latenoon hours of a day while for the premonsoon cases this is at premidnight period with a comparatively higher duration of 30–90 minutes. The most distinctive feature is that the precipitation from the monsoon and postmonsoon thunderclouds is closely associated with SRA while that from the premonsoon thunderclouds is associated with SEA₂. Moreover the amplitude variations of the different features of the premonsoon associated IFIA have been found to be slightly larger than those during monsoon and postmonsoon thunderstorms; the variations of the latter two seasons show some similarity, in general.

(b) *Sea thunderstorms and IFIA*

Hourly occurrences of the onset and end of the night-time effect of IFIA with their percentage values are presented in Table 3.

Table 3. Onset and end of the night-time effect of IFIA.

Phenomenon	Percentage of occurrences within one hour (IST)									
	2000 to 2100	2100 to 2200	2200 to 2300	2300 to 2400	2400 to 0100	0100 to 0200	0200 to 0300	0300 to 0400	0400 to 0500	
Onset	2.9	6.4	13.7	37.7	20.6	12.3	6.4	–	–	
End	–	2.9	3.4	10.3	27.5	26.5	19.1	7.4	2.9	

The above table shows that mostly the night-time effect starts around midnight in between 2300 to 0100 hrs IST (58.3 per cent) while they fall nearly equally on both sides of midnight. For most of the cases, the effect ends after midnight between 2400 to 0300 hrs.

Durations of enhancement, steady level, fall and total life of the night-time effect of IFIA when analyzed show that the enhancement and fall times lie within 50 and 100 minutes respectively while the steady level extends upto 60 minutes. The total life of the effect, which is the sum of the three, varies widely from 30 to 160 minutes. Calculation shows that the correlation coefficient between the duration of enhancement and fall is 0.94 indicating a good correspondence while the correlation coefficients between the duration of enhancement and steady level have been found to be only 0.64. The durations of the steady level, in fact, has got a very small change except during the premonsoon months, March to May, and the seasonal variations in this case is less pronounced.

The relative magnitudes of enhancement as well as fall at 10 kHz in comparison to their respective values at 20 kHz have been determined and are shown in Table 4(a).

Table 4(a). Relative magnitudes of enhancement and fall at 10 and 20 kHz.

Variation	Percentage of occurrences showing relative magnitude		
	10 kHz > 20 kHz	10 kHz = 20 kHz	10 kHz < 20 kHz
Enhancement	94.6	1.9	3.5
Fall	95.5	2.8	1.7

It is seen from the table that in most of the cases the amplitudes of enhancement or fall are greater at 10 kHz than those at 20 kHz. The number of events at 10 kHz where the magnitude of the fall is greater or equal or less than the enhancement are shown in Table 4(b).

Table 4(b). Percentage of occurrences showing relative magnitudes at 10 kHz.

Fall > Enhancement	Fall = Enhancement	Fall < Enhancement
81.5%	15.2%	3.3%

It is evident from the Table that in more than 80% events, the magnitude of fall is greater than the enhancement. Similar results have also been found at 20 kHz.

4. Comparative study

Important characteristics obtained from a comparative study are summarised below :

Land thunderstorms

(i) In course of a land thunderstorm the records of IFIA always exhibit an initial gradual rise followed by a sudden enhancement. Usually, single sudden enhancement is predominant during the monsoon and postmonsoon thunderstorms while double sudden enhancement has mostly been found for the premonsoon cases. A steady recovery of atmospherics start in all the cases after these enhancements.

(ii) The activity of VLF atmospherics reached its maximum around afternoon hours. The duration of the effect is much longer.

(iii) Most of the enhancement as well as the recovery of IFIA for the land thunderstorms are of relatively higher magnitude at 10 kHz than at 20 kHz. The magnitude of the variations may be as large as 60 dB.

Sea thunderstorms

(i) The effect of sea thunderstorms on the night-time records of VLF atmospherics reveals firstly an enhancement followed by a large fall and in between them there is nearly a steady level. The duration of fall varies systematically with the duration of enhancement, thus showing a high correlation between them. Again the rate of enhancement is found to be much greater than the rate of fall.

(ii) The effect on the records of atmospherics mostly starts around midnight in between 2300 to 0100 hrs. IST while the effect ends after midnight. Its duration is considerably shorter.

(iii) In most of the cases the magnitudes of enhancement or fall are greater at 10 kHz than those at 20 kHz. The magnitude of the variations for sea thunderstorms are comparatively lower (upto 45 dB).

5. Discussion

5.1. Related to land thunderstorm :

The gradual rise of IFIA during monsoon thunderstorms seems to be closely associated with the gradual development of the thundercloud and also partly to its gradual approach towards the observing station. Usually the monsoon thunderstorms over Calcutta are closely associated with the easterly wave trough line whose speed of travel is about 10-15 knots [12]. The thunderclouds begin to develop gradually under the joint influence of the southwest monsoon current and the upper easterly wave trough line. After the gradual development of the thunderclouds in its process of approach it culminates into a full fledged thunderstorm during which the sudden enhancement in the record is noticed due to the intense electrical activity in thunderclouds responsible for the onset of a thunderstorm. The first sudden enhancement is associated with the onset of precipitation at the early stage of thunderstorm development. Such early precipitation was, in fact, observed in certain cases when the thunderstorm reached Calcutta. This precipitation, however, ceases quickly until finally the heavy downpour associated with the SRA starts. This apparently marks the final phase of the thunderstorm activity.

The premonsoon thunderstorms over Calcutta are the continuations of those occurring earlier in Bihar (Hazaribag area) or in the western part of West Bengal (Asansol and neighbouring areas). In general, these thunderstorms are associated with a high level (1.5 to 2 km a.s.l.) surface of discontinuity with warm and dry air above cold and moist air [13]. At the initial stage, convection currents are set up irregularly due to insolation. The currents are enhanced with the advance of the day and produce cumulus clouds when they reach the condensation level. Cumulus clouds which are generally of soft fluffy nature sometimes build up to a great height with right conditions of heat and moist air and develop into thunderstorms. If rain begins to fall the clouds are called cumulonimbus, the height of which is decreased with the increasing electrical activity [14] due to vigorous charge separation occurring at that time [15]. The different stages of enhancement in the records of atmospherics, *i.e.*, GRA, SEA₁ and SEA₂ may be attributed closely to this process of forming cumulonimbus structure. The time delay between GRA and the thunderstorm arrival is easily explainable as it would depend widely on the distance of origin, the degree of development and the movement of the particular thunderstorm towards the observing station. The start of second sudden enhancement before the onset of nor'wester over Calcutta, for a major number of cases, is understandable as it would depend mainly upon the rate of travel of the active thunderstorm centre from the place of its origin to the observing centre Calcutta. The rate of travel is of the order of 30 to 40 m.p.h. from Asansol or Hazaribag towards Calcutta and a thunderstorm sequence starting from Asansol would travel to Calcutta within about three hours while that from Hazaribag within a period of seven hours [16].

The sudden enhancement of IFIA during a postmonsoon thunderstorm seems to be closely associated with the initial stage of its development while in the final stage the observed steady recovery starting with a sudden decrease associated with local rainfall may be explained by considering the vanishing of the bipolar structure of thundercloud due to falling out of charged rain. The variational nature of IFIA of the postmonsoon thunderstorms is thus found to be somewhat similar to that observed during the monsoon period. The time difference between onset of GRA and SEA₁ during postmonsoon thunderstorms is around 1 hour only. This suggests that the developmental stage of a postmonsoon thundercloud is of shorter duration compared to that of monsoon and premonsoon cases. Takeuti *et al* [17,18] also reported that the thunderstorm activity during the winter season is very weak compared to that during summer season.

5.2. *Related to sea thunderstorm :*

The meteorological conditions for thundercell development over the sea are different from those over the land and the characteristics of the sea-storms therefore, reveal some differences from those of land storms. It is now known that the frequency, intensity and lifetime of sea-thunderstorms is smaller than the respective values of land thunderstorms [19]. The maximum activity of land storms usually occurs at afternoon hours of a day, while over the

ocean it occurs around midnight [20]. The temperature over ocean, in fact, rises from evening to midnight when the activity of the storm starts [21,22]. Maximum activity of oceanic storms at night have been reported by many authors from time to time [17,23,24]. Krumm [23] and Heydt [24] reported that the greatest activity occurs at local midnight and this has been supported by Takeuti [17] who made his observations over the Pacific near Japan. The cause for the occurrence of storms at night-time over sea is possibly due to the instability in the top part of cloud by radiative cooling, which encourages droplet growth by mixing of droplets at different temperatures [25,26]. In the developing stage of a storm the cloud is accelerated upward. The updrafts increase with elevation and the cloud builds rapidly to a height during which large amount of cloud droplets, raindrops and snowflakes accumulate in the cloud [27]. The developing stage of the sea-storm originating in the Bay of Bengal, appears to be related to the enhancement of night-time effect of atmospheric.

In the mature stage of the storm, updrafts and downdrafts exist side by side. The falling rain or snow coming from the colder air aloft, cools the downdraft and after a short time, a heavy downpour begins. At the end of the mature stage, *i.e.* at the dissipating stage the downdrafts gain over the updrafts and the rain intensity gradually decreases [28]. The steady level of atmospheric after the enhancement is perhaps associated with the electrical activity of the mature stage of a thunderstorm while the fall might be associated with the final rainfall from the thunderclouds.

The magnitude of fall has been found to be greater than the magnitude of enhancement, in general. This may be explained partly by the significantly lower activity of atmospheric after midnight as reported by Aiya [20]. In our results, it has been observed statistically that the start of the enhancement and the end of the fall in most of the cases occur in between 2300-2400 IST and 2400-0300 IST respectively. Thus, the lower level of atmospheric at late night hours may be considered as one of the contributing factors for a higher magnitude of fall than that of the enhancement.

The fact that most of the night-time effect in sferics record related to sea thunderstorms as well as the variations like GRA, SEA, SRA related to land thunderstorms at 10 kHz have a greater magnitude than that at 20 kHz may be explained by the existing knowledge of cloud-to-land and cloud-to-sea discharges. Takeuti and his group [7,17] observed the discharges over land and on the ocean. From a series of actual photographic documents, they concluded that the frequency distribution of the multiplicities of return stroke for the cloud-to-sea and cloud-to-ground discharges are similar and the distribution of time intervals between adjacent return strokes for cloud-to-sea discharges is similar to that for the cloud-to-ground discharges both located in the tropics. The saline sea water in the Bay of Bengal is known to be more conductive than that of the surrounding land. So, there is no practical difficulty in the occurrence of cloud-to-sea discharges on the sea in the Bay of Bengal in presence of overhead thunderstorms. The close similarities of the above two

discharges indicate that the frequency spectrum of atmospherics as obtained by Kimpara [29] from an extensive observations of cloud-to-ground discharges must also hold good for the cloud-to-sea discharges. According to him, atmospherics originating from return strokes has a peak intensity at about 10 kHz. The observed higher magnitude of the effect at 10 kHz is therefore, reasonably expected.

6. Conclusions

From the study of the detailed features of the unusual enhancement and subsequent decay of IFIA it appears that the time period of night-time changes due to discharges accompanied by sea thunderstorm is rather low than the variational time of IFIA observed during land thunderstorm. The peak activity of land storms usually occur during the local afternoon hours, yet there are occasions when night-time land storms of comparatively weaker nature have also been formed which in turn produce the night-time effect in IFIA. Again as the radar was operated at an interval of one hour, any intermediate effect of shorter duration may be missed in the polar record used in this study which may be solved by a continuous PPI record.

The various stages of enhancement of IFIA could not be explained in terms of better propagation conditions from the sporadic E-layer produced by a lightning discharge originating in thunderclouds [30,31]. This is due to the fact that at 10 or 20 kHz the ionospheric propagations during daytime would be governed mainly by reflection from the D-region and the ionization of this region is not likely to be affected by thunderstorm because of high collision frequency at the height involved. On the other hand, it is interesting to note that the large enhancement of IFIA due to intense electrical activity within sea thunderclouds is influenced by a better VLF propagational condition during night-time in the absence of D-region. At night hours with noise propagation by the E-region, there are very small propagation losses [32] and as a result, the night-time level of VLF atmospherics show a higher value than that observed in daytime. This factor has, in fact, a significant contribution to exhibit the night-time effect in the records even for a comparatively weaker storm.

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